Upper ocean thermal structure from high-density XBT lines in the Atlantic Ocean

Molly Baringer, Gustavo Goni, Silvia Garzoli and Qi Yao

National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida, USA

www.aoml.noaa.gov/phod/data/hdenxbt

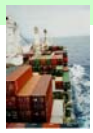
Background

Five high density XBT lines are maintained by NOAA/AOML:

- AX07 ( ) is located nominally along 30°N extending from the Straits of Gibraltar in the eastern Atlantic to the east coast of the United States at Miami. This line as been operating since 1995 with a brief false start in 1994. Sampling started as twice per year, then was augmented to four times per year in 1996. To date, 33 sections have been completed.
- AX10 ( ) runs between the New York harbor and Puerto Rico. This line has been operating since 1997. Sampling started as four times per year. As of February 2004, 27 sections have been completed
- AX08 ( ) samples across the Tropical Atlantic with emphasis between 20°N and 20°S. This line has been operating since December 2000. Starting in 2002, cruises are scheduled four times per year. As of March, 2004, 10 cruises have been completed.
- AX18 ( ) runs between 20°E and 60°W along 35°S, a line which links South Africa with Buenos Aires, Argentina. This line operated twice a year during the first two years, and it is now scheduled to run four times a year. To date four sections have been completed and one is currently (April 2004) underway.
- AX25 ( ) runs between South Africa and Antarctica very close to a JASON-1 altimeter groundtrack. This is the newest AOML line and it will be operated twice a year. One section has already been completed.

	AX07	AX10	AX08	AX18	AX25	Total
1994	131					131
1995	466					466
1996	709	07				896
1997	914	373				1287
1998	717	357				1074
1999	910	375				1285
2000	665	290	157			1112
2001	933	423	154			1510
2002	920	492	1004	367		2784
2003	940	300	1033	377		2650
2004	1079	1047	341*	180*	188*	9301
Total	7702	2812	2689	924	188	14115

* Deployments until mid-April.



More than 13,000 XBTs have already been deployed since 1994. The table above shows the number of launches per year and per line

Introduction:

NOAA/OGP funds five high-density XBT lines maintained by NOAA/AOML: 1) **AX07**, located along 30°N extending from the Straits of Gibraltar to Miami, 2) **AX10**, running between New York and Puerto Rico, 3) **AX08**, sampling across the Tropical Atlantic with emphasis between 30°N and 30°S, 4) **AX18**, running between South Africa and Argentina along 35°S, and 5) **AX25**, sampling between South Africa and Antarctica. These five XBT lines have been chosen to capture and monitor thermal properties within the Atlantic. The **AX07** and **AX18** lines have been selected to monitor the net meridional flow in the upper ocean. **AX10**, **AX08** and **AX25** are meridional lines that were selected because they cross important highly variable ocean currents, namely the Gulf Stream, the numerous Equatorial Atlantic Currents and the Agulhas and Antarctic Circumpolar Currents respectively. All XBT lines are valuable in providing estimates of the mean and time dependent temperature fields with sufficiently close spacing to sample the mesoscale field (XBTs spaced between 30-50km). They all sample various aspects of the overturning circulation and hence provide useful data on heat transport and interbasin/cross equatorial exchanges. To date, more than 13,000 XBTs have been deployed in its high density mode in the Atlantic Ocean.

Objectives:

Some of the objectives of these lines are to characterize the structure of upper ocean currents and eddies, investigate the spatial and temporal variability of geostrophic currents, measure seasonal and interannual variations in the transport of mass, heat, and freshwater; provide in-situ data for model testing and assimilation. Typical users of these data sets are Operational Centers such as NCEP, the Navy, ECMWF for initialization of seasonal-interannual forecasts, modeling centers such as GFDL for model validation, NOAA for validating altimetric estimates of Tropical Cyclone Heat Potential, and the national and international oceanographic community for basic research.

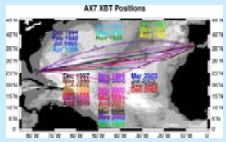
Data obtained from these four high density lines can contribute to an assessment of the state of the climate by providing:

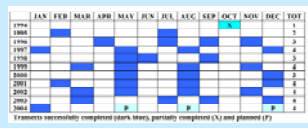
- quarterly estimates of upper ocean heat and mass transport, which can serve as an index or benchmark for the upper ocean circulation.
- estimates of the state of the thermal mass field (e.g. depth of the thermocline, statistics of the variability, etc) that must be simulated appropriately by numerical prediction models.
- subsurface temperature anomalies along repeated locations and particularly through fast moving boundary currents.

Logistics:

These XBT lines require the aid of Volunteer Observing Ships (VOS) willing to have a technician aboard to deploy XBTs. These lines meet WOCE criteria for high resolution deployment providing temperature profiles every 10-30 km near currents, and every 50 km elsewhere, down to a depth of approximately 800 m. Such fine horizontal sampling requires a technician on board the ship and the use of an auto-launcher designed to launch up to 6-8 XBTs fired remotely via computer-controlled software.

The XBT autolauncher system was designed and built at NOAA/AOML and has been in numerous oceanographic applications since 1995. The autolauncher system consists of the launcher and an associated computer system that controls all the launcher functions and logs the data. A GPS receiver is interfaced to the computer and provides navigation information. IN addition, a Geostationary Environmental Satellite (GOES) system transmitter is used to transmit the data to shore in real-time for distribution over the Global Telecommunications System (GTS). The launcher is mounted to the ship's rail near the stern. Launcher typically have six or eight launch tubes that are preloaded with XBTs that can be launched at programmable locations as the ship steams along its course.

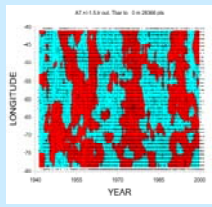




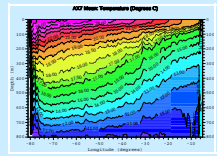
This line provides a section near the center of the subtropical gyre and the Straits of Florida. A typical temperature section shows the characteristic shape of the subtropical gyre with isotherms sloping up towards the east. For instance, the main thermocline consists of closely spaced isotherms between 12° and 17°C that slope up from depths of 500-700 m near 70°W to depths of 100-400 m near 10°W. This slope implies a vertical shear in velocity with near surface water moving southward relative to deeper water. The center of the thermocline bowl is located where the isotherms are at their deepest. Along AX7, all isotherms between 17.5° and 11°C are deepest near 72°W in the mean. Westward of this mean position, the isotherms slope sharply upward across the Antilles and Florida Currents, while eastward the isotherms shoal more gradually across the rest of the North Atlantic. Below the main thermocline lies the quiescent shadow zone in the east, where isotherms flatten.

There is also a suggestion of warm Mediterranean outflow water crossing the section below 600 m east of 20°W, where the deep isotherms slope downward. Above the main thermocline in the west lies the weakly stratified 18C Subtropical Mode water (between the 17° and 19°C isotherms). The depth between these isotherms increases towards the west, indicating a large mass of water with fairly uniform temperature. This Mode water is formed in the winter just south of the Gulf Stream front to the north of this section. Above this Mode water lies the seasonal thermocline with temperatures that range from 19° to 30°C. The mean temperature section shows that these isotherms outcrop uniformly westward across the surface.

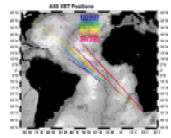
This line effectively encloses the entire North Atlantic. The latitude is useful for monitoring heat flux variability in the Atlantic because it is near the center of the subtropical gyre and is the latitude of maximum poleward oceanic heat transport. Heat exchange with the atmosphere occurs north of this section. Hence, heat transport through this latitude serves as an integral constraint on the net surface heat flux north of this line.



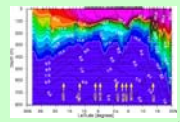
Sea surface temperature anomalies obtained from BT and XBT observations showing a ten year signal.



A mean temperature section along AX07 shows the east to west deepening of the main thermocline layers with temperatures between 17° and 12°C.

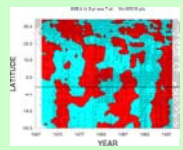


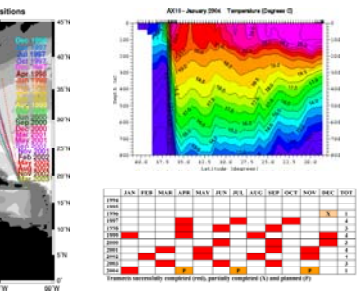
The transport of the zonal currents in this region are highly variable. The implementation of this line is geared towards providing additional information on the spatial and temporal variability of the above currents. Data from temperature sections obtained along this line, between 20°N and 20°S, with salinity profiles derived from historical T-S relationships, are used to estimate the location and geostrophic transport of each of these currents. Altimeter-derived sea height anomaly fields are used to explore the relationship between the hydrographically-derived dynamic heights with the altimeter-derived sea heights. Additionally, salinity profiles obtained from profiling floats deployed during the December 2000 transect are used to investigate the uncertainty of the dynamic height estimates caused by using salinity obtained from historical T-S relationships.



Temperature section for the September 2001 transect with the major currents identified from the slope of the isotherms indicated below.

.The XBT line **AX08** crosses the tropical Atlantic in a NW-SE direction between North America and South Africa. Historical data along **AX08** and other historical temperature observations in the tropics exhibit long period signals, possible decadal and multi-decadal signals. It has been hypothesized that this decadal signal may have a cause and effect relationship to atmospheric and oceanic signals. Given the importance of the tropical Atlantic in climate variability, and the scarcity of observations in this region, data obtained from the measurements along this line are key to improving the climate forecast by improving the subsurface temperature coverage in the tropical Atlantic.



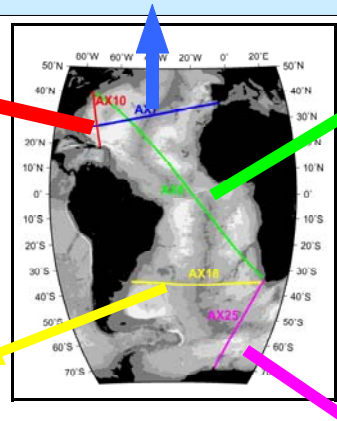


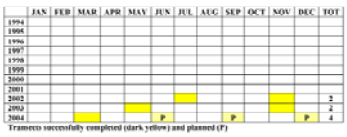
This Line provides a meridional view through the subtropical gyre, and reveals more complicated and variable patterns . This line effectively closes off the eastern seaboard (between New York and Puerto Rico), where temperature anomalies have the most influence on the atmosphere.

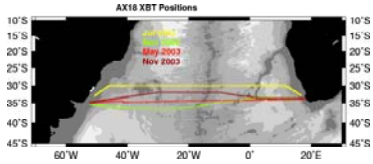
Isotherms in the main thermocline slope downward towards the north to the center of the subtropical gyre near 34N, with the 17°C isotherm reaching depths as great as 700 m. North of this, isotherms rapidly slope upwards through the Gulf Stream. The northern edge or 'wall' of the Gulf Stream is often delimited by where the northernmost position of the 15°C isotherm slopes below 200 m (which also corresponds generally to the surface velocity maximum). Farther south, this isotherm slopes upwards from 500-700 m. The southern edge of the Gulf Stream is sometimes delimited by where the 15°C isotherm slopes below 500 m.

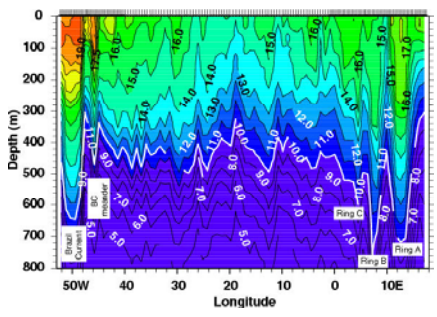
Above the main thermocline lies the large volume of 18°C water south of the Gulf Stream. The wedge of water between the 17°C and 19°C isotherms thickens from south to north, where it reaches a maximum of about 500 m when it outcrops Along this section, 18°C water has even lower variability than along AX07.

In the subtropical gyre, the slope of the isotherms is generally consistent with the eastward flow of the Gulf Stream (near 36°N) and broad westward flow in th south. Further, there exist strong, variable recirculations that can be seen just south of the Gulf Stream. Also cyclonic and anticyclonic rings formed through instabilities in the Stream can appear along section.



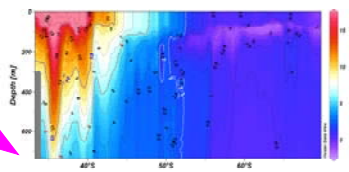


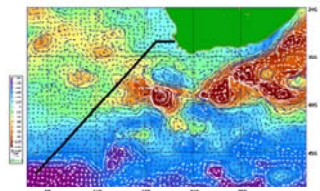




The vertical thermal structure observed along this line depicts the mesoscale features, particularly those associated with the Brazil Current, on the west, and to the Benguela Current and Agulhas rings, on the east. The temperature section of November 2002 (left) shows between 60°W to 10°W the expected general West-East slope in the isotherms characteristic of the Subtropical gyre. The isotherms of 10°C is highlighted in both sections, as they are generally used to investigate the Brazil-Malvinas Frontal motion and the water mass anomaly carried by Agulhas rings.

Measurements along this line will provide important data to investigate of changes in the upper ocean heat content and SST in the interannual time scale. In addition, by exploiting the relationship between the upper ocean temperature and dynamic height, XBTs observations can be used to infer velocities in the Southern Ocean, where salinity changes are important.





Temperature section along the first AX25 transect carried during February-March 2004. The dashed isotherms represent the subsurface axis of the Subtropical Convergence (blue, 10°C), Subantarctic Front (red, 10°C) and Antarctic Polar Front (white, 2°C). The deepening of the isotherms north of 40°S correspond to the meanders of an Agulhas ring.

AX25 cruise transect, carried by the R/V Agulhas as part of the Good Hope Project, are superimposed to the geostrophic currents derived from altimetry for February 26, 2004. This transect crosses the western edges of an Agulhas ring north of 40°S.

This project is funded by NOAA/OGP. Some portions of the results presented here were obtained with the collaboration of: Dr. Robert Molinari, Ariel Troisi, Robert Roddy, Steve Cook, Ben Kates, Grant Rawson, and Jim Farrington.